139-145

REVIEW PAPER

A REVIEW OF NANOPARTICLE EFFECTS ON ALUMINUM ALLOYS AND WELDABILITY

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Abstract: The ongoing trend for reducing energy consumption and emissions has led scientists to investigate new methodologies for improving lightweight materials in order to make them more qualified for different types of structural engineering applications The most common lightweight materials used in structural assembly are high-strength aluminum alloys that show certain difficulties when welded and require special techniques for achieving homogenous crack-free welded joints. Nanoparticle reinforcement of aluminum alloys is a promising methodology for phase-controlling solidification of welded joints. The microstructure and properties of these welds are determined by the nanoparticles introduced and the welding parameters used during the welding process. The aim of this paper is to go over recent publications on nanoparticle reinforcements of aluminum alloys and their use in welding production. It summarizes the effect of different nanoparticle reinforcements on grains and properties of welded joints and discusses further development and application of hybrid nanostructured aluminum alloys.

Keywords: *nanoparticle, nanostructure, lightweight, aluminium, welding.*

1. INTRODUCTION

Aluminum alloys are nonferrous metals that have been widely used in mechanical applications such as structural applications and the aerospace, automobile, marine, and defense industries [1][2]. This is due to the fact that aluminum alloys have a good combination of low density, high specific strength, high corrosion resistance, good machinability, good creep and chemical resistance, and excellent recyclability, as well as being a low-cost manufacturing process [1][3]. However, there are some drawbacks that limit their application, such as a higher coefficient of thermal expansion (CTE), poor hardness and wear performance, particularly in load bearing and abrasion applications [3]. There is a constant need to improve these alloys, and there are a variety of methods for doing so. Some well-known techniques include solid solution and precipitation strengthening, work hardening, and grain boundary strengthening [1]. The Al matrix can be reinforced with the addition of suitable ceramic particles (SiC, Al_2, Ti, O_2, and B_4C) which are micro-sized, but the result did not deliver the expected strength outcome [3]. In general, most of the mechanisms for reinforcements used did provide a variety of aluminium alloys, but the strength achieved did not excide over 700MPa [1]. This is why researchers have turned to new studies involving nanoparticles, as nanotechnology has proven to be effective in many other materials. The reinforcement mechanisms that use nanoparticles such as Orowan mechanism, thermal discrepancy, and load transfer mechanisms are used for strengthening of cermet [3]. Some of the approaches used by researchers for strength reinforcements of aluminum alloys include single reinforcement with particles of SiC, Ti_2, and SiC, but the results show that while this methodology improves some properties, it does not improve others such as corrosion resistance or thermal expansion [3]. As a result, single reinforcement is not providing satisfactory results; however, the use of hybrid composite reinforcements may be the solution.

High-strength Al alloys are created by either producing ultra-fine-grained nanocrystalline Al alloys with refined microstructures or producing defect-free Al-based metallic glasses (grain boundaries, dislocations) [1]. High strength with acceptable plasticity can be achieved with a refined or defect-free crystal structure. However, there are some issues that need to be researched and addressed further. For example, Al-based metallic glasses have poor formability and a non-equilibrium state, as well as poor thermal stability at higher temperatures [1]. Another method for producing nano-crystallized material is to crystallize amorphous solids under special heat conditions, but this does not provide the microstructure stability and thus the achieved property enhancements [1]. As a result, further strategies for the fabrication of Al-based alloys with super high strength and other desirable properties are required. Many studies on the use of various reinforcements have demonstrated that good properties can be achieved [1]. Comparison between aluminum alloys with and without reinforcements are done, reporting differences up to 80% in strength and hardness, and improvements in wear resistance. Here we summarize some of the results obtained from experiments on aluminium alloy reinforcement with nanoparticles. Furthermore, because aluminum alloys are important materials for structural engineering and welding is the primary joining process used for their structural assembly, discussions on the weldability of aluminum alloys and improvements to welding processes using nanotechnology are discussed.

2. NANOPARTICLE REINFORCEMENT OF ALUMINIUM ALLOYS AND WELDABILITY

Researchers investigating the effect on microstructure and material properties have used various combinations of nanoparticle reinforcement of aluminum alloys. For example, in Al 6061, two different nanoparticle combinations, 2% SiC+3% Al_2O_3 and 2% SiC+3% TiO_2, are introduced with a ball mill at 300rpm for 1 hour and then heated up to 650 °C in a stir casting machine, after which C_2Cl_6 is added to degass the alloy [3]. The preheated alloy, nanoparticle mixture, and wetting agent are added to the liquid at a constant stirring speed for 5 minutes, and after cooling to a semisolid state at 500 °C, heating is introduced again at 750°C with constant stirring to reduce cluster formation and improve performance. The preheated alloy, nanoparticle mixture, and wetting agent are added to the liquid at a constant stirring speed for 5 minutes, and after cooling to a semisolid state at 500°C, heating is introduced again at 750°C with constant stirring to reduce cluster formation and improve wettability. Nanoparticles can penetrate by breaking agglomerates in this manner, resulting in a more homogeneous distribution [3]. To disperse nanoparticles uniformly, a high-frequency ultrasonic probe can be inserted into the liquid for 5 minutes. The next step in the process is double squeeze casting for high-density alloys, which results in low relative porosity but high grain refinement with a nominal level of nanoparticle agglomeration. Preheating the die is used for stress relief or lowering stress concentration. The produced specimens are then heat treated for further improvements of the microstructure. After testing the properties, it was discovered that increasing the ceramic particles in the alloy increased strength, hardness, wear, and corrosion resistance [3].

Aluminium-matrix composites are useful in engineering because they have higher specific stiffness and strength than unreinforced alloys, as well as higher wear resistance. Several properties, such as hardness, strength, fracture toughness, and electrical conductivity, are improved with reinforcement, making TiB_2-Al_2O_3 composite suitable to produce cutting tools, wear-resistant substrates, and lightweight armor. Aluminium Alloy Matrix/TiB_2/Al_2O_3 hybrid nanocomposites for surface applications can be created using Friction stir processing (FSP) [4]. The tool is used to distribute hybrid ceramic nanoparticles on the surface of an aluminum-based alloy [4]. Some studies have been published on the use of graphene as reinforcement in various forms such as particulate, nanoplatelets, and nanosheets [5]. In the literature, aluminum matrix reinforced with graphene nanosheets via powder metallurgy, graphene nanoplatelets via mechanical alloying, powder processing route, and squeeze casting have all been reported [5]. When microstructural analysis of AA7050-graphene composite samples was performed for properties analysis, it was discovered that increasing the graphene content first enhanced and then deteriorated the strengthening effects. There are functional groups on the carbon fillers, and the forms of bonding at the interface of aluminum matrix composites during the molecular mixing process are advantageous to load transfer between the matrix and reinforcement. Interfaces and strong interfacial bonding between the graphene reinforcement and the aluminum alloy AA7050 metal matrix are critical in determining composite tensile strength [5]. SEM images of stir cast and squeeze cast AA7050 - graphene composite material structures are shown in Fig.1, revealing that the interface information of these composites is continuous and free of gaps or impurities [5].

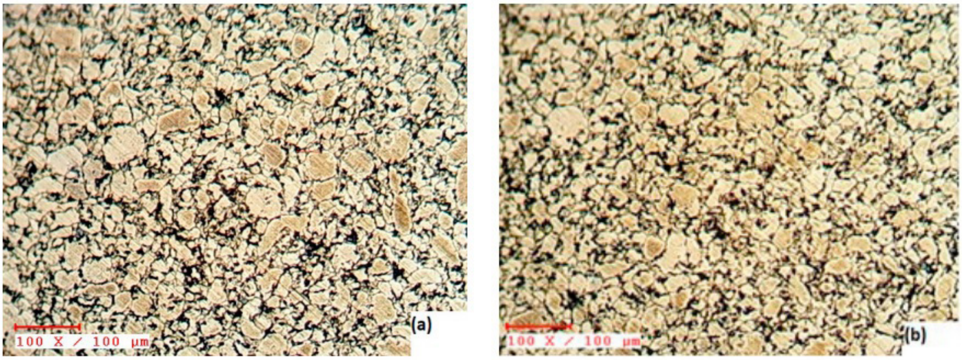

Figure 1 *SEM images of cast AA7050 - graphene composite material a) stir cast b) squeeze casting [5].*

Furthermore, the aluminum 7075 metal matrix can be reinforced with silicon carbide using the stir casting method, which distributes the particles uniformly in the metal matrix material. The mechanical properties can thus be improved, and this is dependent on the weight percentage of silicon carbide particles in the matrix. On the other hand, as the weight percentage of silicon carbide increases, so does the wear rate, and as the weight load increases, so does the coefficient of friction [6]. The other nanoparticles used for nanoscale reinforcement include aluminum oxide (Al_2O_3), tungsten carbide (WC), titanium diboride (TiB_2), silicon carbide (SiC), zirconium boride (ZrB_2), titanium carbide (TiC), and boron carbide (B_4C), all of which are commonly used in aluminum hybrid composites to improve mechanical properties such as tensile, compressive, and hardness [7].

Welding is the primary method of joining aluminum alloys, which can be solid (friction stir welding) or liquid (arc welding, gas metal arc welding and tungsten metal arc welding) [2]. Arc welding for high-strength aluminum alloys, particularly AA70755-16, has been the subject of extensive research, and these approaches to optimizing welding parameters or finding new metallurgical solutions have been demonstrated to be ineffective [8]. It has been demonstrated that nanoparticles not only improve metal matrix properties but also have a significant impact on grain size and solid fraction during solidification, making the incorporation of nanotechnology into solidification processes such as casting and arc welding promising. Filler materials containing nano reinforcement are used to improve mechanical properties in the welded zone. Fig 2., shows parts of welds performed with three different filler materials [8]

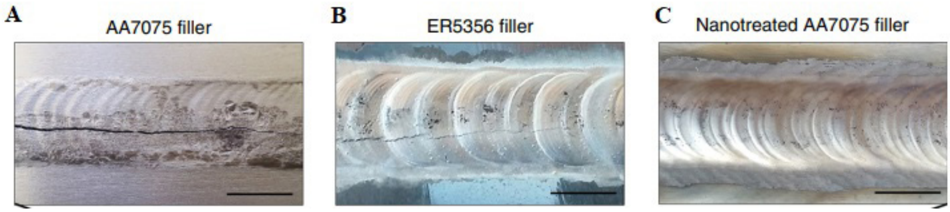

Figure 2 *Gas tungsten arc welding of AA7075 with different filler metal.*

In welds performed with conventional filler materials AA7075 and ER5356, macroscopic solidification cracks are visible in the melting zones of the beads. The weld produces an even weld bead with no cracking when C AA7075 + 1.7 vol% TiC is used as filler material [8]. The AA5083 alloy has good corrosion resistance, mechanical properties, and fatigue fracture resistance; however, welding with gas tungsten arc welding (GTAW) of AA5083 alloy can result in coarse grain formation along the HAZ, which leads to softening in the HAZ region [9]. The dissolution of strengthening precipitates and the high heat input cause joint failure in the weld metal [9]. According to the most recent research findings, reinforcement particles in FSW can improve weld properties and microstructure formations, reduce joint defect formation, and improve the mechanical and corrosion resistances of dissimilar 5x series Al joints. This is accomplished through dynamic recrystallization, which results in the formation of a new nucleation site, reducing grain growth, and acting as reinforcement against corrosive environments [9]. Nano-powder technologies are also beneficial when used as a coating on aluminum alloys and welded joints to reduce the concentration of stress (defects) [10].

3. CONCLUSIONS

Nanoparticles can be used as reinforcement particles in aluminium alloys due to their small size, which results in uniform dispersion grain refinement and improved properties. In fusion welding nanoparticles coated with base metals on electrodes produce joints with improved microstructural features and mechanical properties. Various researchers have estimated the enhancement of mechanical, and tribological properties of the material with single or multiple nano reinforcements.

In conclusion, the resulting microstructures, which are made up of isolated nanoscale fcc-Al and intermetallic compounds, have high strength at both room and high temperatures. This is due to the creation of unique hybrid microstructures via processing condition optimization and the composite structure. The effect of confinement among the nano-sized fcc-Al and intermetallic phases are the reason for the high strength. However, there has been very little research and investigation into the welding of nanoparticle-reinforced aluminum alloys up to this point. Furthermore, reinforcement particle combinations are restricted, with no exploration into alternative possibilities. Special attention should be given to the effect of nanoengineered materials on the stability of the consumable electrode in the welding process, as well as the effect of these materials on the mechanical properties and chemical composition of the welded joint. The technical-economic parameters of the process involving nanomaterials also must be ascertained.

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ПРЕГЛЕД ЕФЕКТА НАНОЧЕСТИЦА НА АЛУМИНИЈУМСКЕ ЛЕГУРЕ И ЗАВАРИВОСТ

Елисавета Дончева, Мартин Петрески

Сажетак: Тренутни тренд смањења потрошње енергије и емисија је навео научнике да истраже нове методологије за побољшање лаких материјала како би их учинили квалификованијим за различите типове грађевинских апликација. Најчешћи лаки материјали који се користе за склапање конструкција су легуре алуминијума високе чврстоће које показују одређене потешкоће у заваривању и захтијевају посебне технике за постизање хомогених заварених спојева без пукотина. Ојачање алуминијумских легура наночестицама је обећавајућа методологија за фазну контролу очвршћавања заварених спојева. Микроструктура и својства ових заварених спојева одређују се унесеним наночестицама и параметрима заваривања који се користе током процеса заваривања. Сврха овог рада је преглед новијих публикација о ојачавању алуминијумских легура наночестицама и њиховој употреби у производњи заваривања. Описује утицај различитих наночестица ојачања на зрно и својства заварених спојева и разматра могућности даљег развоја и примјене хибридних наноструктурираних легура алуминијума.

Кључне речи: наночестице, наноструктура, лака тежина, алуминијум, заваривање.